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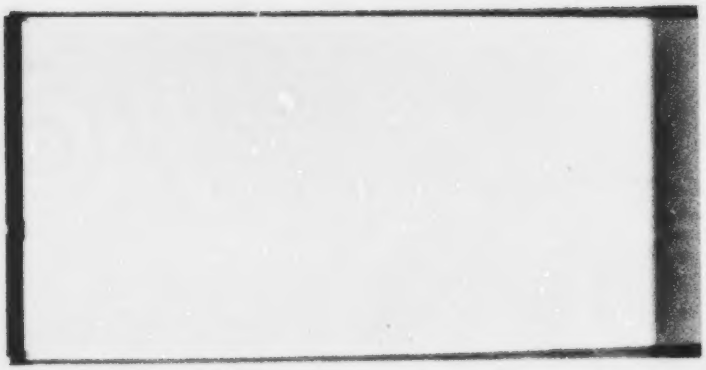

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A FIELD STUDY OF THE EFFICACY OF AN ILLUMINATED AIR BUBBLE CURTAIN TO DIRECT FISH

Report No 84-310-K

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Biologist
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ABSTRACT

In situ tests were conducted on the ability of an angled air bubble curtain to direct fish entrapped in the Nanticoke TGS forebay channel. Irrespective of the angle of the air bubble screen or the presence of surface lights, fish were not significantly directed from one side of the channel to the other. Catch results suggested that fish may have preferred to move along the south side of the channel near the bottom under control conditions (no bubble screen or lights). A variety of factors including differential current velocities and fish distribution within the channel possibly influenced the results obtained.

job	file	date	report no.
740634-118-492	837.315	October 12, 1984	84-310-K

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EXECUTIVE SUMMARY

A FIELD STUDY OF THE EFFICACY OF AN ILLUMINATED AIR BUBBLE CURTAIN TO DIRECT FISH

W.E. Carey
Biological Research Section
Chemical Research Department

The objective of this study was to test the effectiveness of an angled, illuminated air bubble system in directing viable intake forebay entrapped fish. Tests were carried out at the request of Design and Development Division during September 19-23 and 27-30, and November 21-24, 1983 in the Nanticoke Thermal Generating Station (TGS) intake forebay.

Regardless of the type of treatment, there was no significant redirection of fish within the forebay by the air bubble system. Movement of fish along the sides of the channel may partially account for the negative results since more fish were captured in bottom gill nets set at the south side than at the north side of the forebay even during control conditions (no bubbles or lights used).

Factors which may have influenced the results were water velocity, illumination, water level, fish distribution within the channel, and the gap between surface and bottom nets. If the study is to be redone care should be taken to select a location with a more uniform water velocity profile, to completely illuminate the air bubble system, and to sample the entire water column.

job	file	date	report no.
740634-118-492	837.315	October 12, 1984	84-310-K

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To Dr. W.R. Effer
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A FIELD STUDY OF THE EFFICACY OF AN ILLUMINATED AIR BUBBLE CURTAIN TO DIRECT FISH

1.0 INTRODUCTION

The development of effective fish diversion systems to reduce fish impingement on power station intake screens is the primary objective of the Capitalized-Once-Through-Cooling (COTC) Retrofit Program. Recent laboratory studies have suggested that an illuminated air bubble barrier system may be an effective component of a fish handling scheme (Ontario Hydro Research Division Reports No 82-362-K and No 83-266-K).

This study, requested by ES&A as part of the COTC program, investigated the efficiency of an angled, illuminated air bubbler system in directing viable intake forebay entrapped fish. The study site was changed from the Pickering NGS 'A' intake channel to the Nanticoke TGS intake forebay because of the paucity of entrapped fish at the former location during late August/early September, 1983.

2.0 METHODS

2.1 Air Bubble Screen

Compressed air at approximately 345 kPa (50 psi) was supplied by a feed line from the main compressor system at Nanticoke TGS, near Pumphouse No 1 (Figure 1). Air was blown into a 23 m PVC pipe slotted with T-bar manifold attachments to deliver air to 5 pieces of bubble diffuser (each 4.5 m long) connected end to end. Each diffuser portion was constructed of an inner flexible hose with approximately 0.5 cm pores spaced 2.5 cm apart and an outer nylon-weave sheath which served to release air in fine bubble streams through multiple openings. Foam-like material separated the inner and outer surfaces, allowing air to spread out evenly over the length of each diffuser portion. The entire PVC air line and diffuser assembly was clamped together and anchored to the bottom at the desired angle (45° or 30° to the north side of the forebay channel) with concrete blocks.

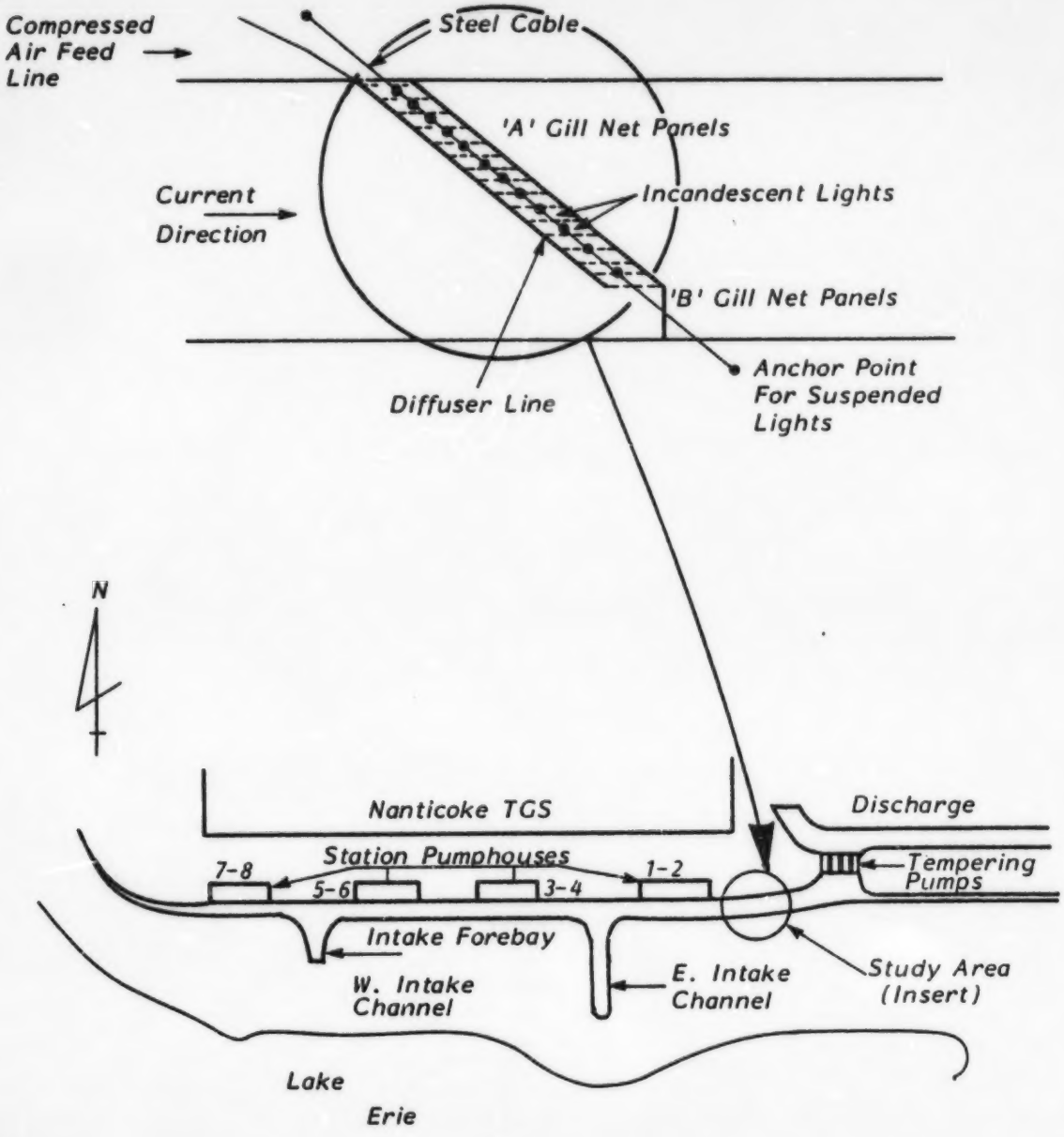

FIGURE 1

TOP VIEW OF NANTICOKE TGS FOREBAY AND STUDY AREA

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When air was flowing a diffuse band of air bubbles about 3.0 - 4.0 m wide could be seen breaking the water surface at a distance of approximately 3.0 m downstream from the diffuser line. The air bubble stream was not completely uniform along its length (at the surface). Air pressure was regulated by an on-line gauge system situated on the north shore of the forebay channel.

2.2 Illumination

The air bubble screen was illuminated by suspending a single row of 12 submersible incandescent floodlights midway between the diffuser line and the area where bubbles broke the surface (Figure 1). The lights were spaced about 1.5 m apart and positioned about 1.0 m below the water surface such that light shone downward. A length of steel cable (about 45 m long and 1.3 cm in diameter) held taut across the channel above the water surface was the main support line for the lights. Measured light intensities from surface to 3.0 m depth at distances of 1 m and 2 m upstream of the light source were (in units of $\mu E.m^{-2}.s^{-1}$):

Depth (m)	Distance from Source (m)	
	1	2
0.0	0.01	0.08
0.6	0.20	0.08
1.2	0.46	0.07
1.8	0.46	0.15
2.4	0.31	0.15
3.0	0.19	0.08

Thus light levels decreased downward and outward from the light source. Light intensities were not measured towards the bottom of the channel due to instrument problems. However, light intensities at a depth of 8.0 m were calculated using an extinction coefficient derived from the above values. Light intensities 1 m and 2 m away from the centreline of the light source were estimated to be 0.009 and 0.002 $\mu E.m^{-2}.s^{-1}$, respectively. Consequently, the lower portion of the bubble screen probably received less illumination than the top portion.

2.3 Gill Net Array

Fish movement was monitored by a system of gill nets arranged behind (downstream of) the bubble screen (Figure 2). Two pairs (A and B) of 3.7 cm stretched mesh monofilament nylon gill nets were set during each test. The 'A' pair of nets consisted of surface and bottom gill net panels, each about 23 m long and set across the channel at approximately the same incline as the bubble screen. Both 'A' gill nets were placed about 2 m downstream of the surface turbulence created by bubbles, and the bottom net was directly below the surface net (Figure 2).

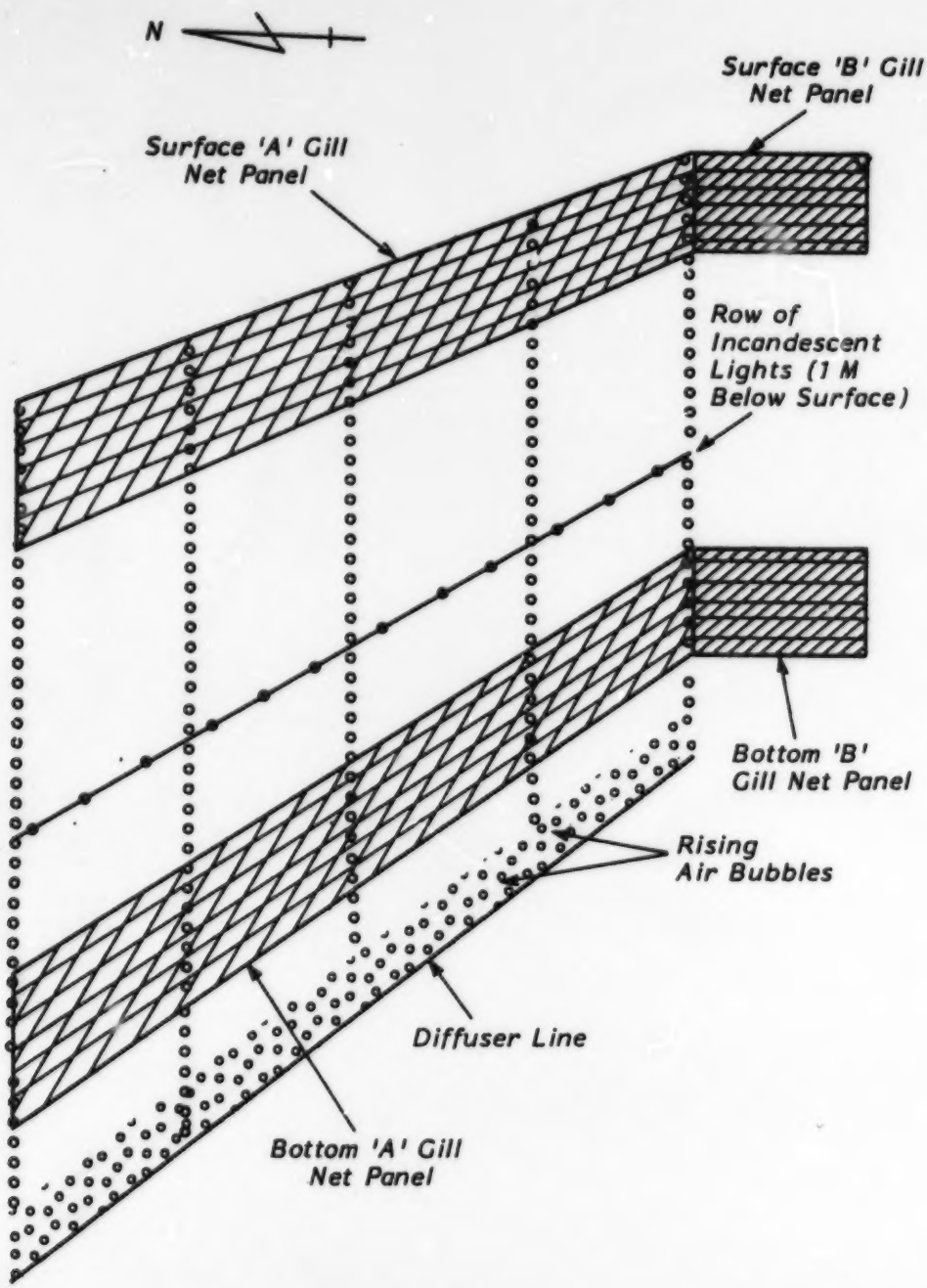
N
Surface 'B' Gill Net Panel
Surface 'A' Gill Net Panel
Row of Incandescent Lights (1 M Below Surface)
Bottom 'B' Gill Net Panel
Rising Air Bubbles
Diffuser Line
Bottom 'A' Gill Net Panel

FIGURE 2

SIDE VIEW OF THE EXPERIMENTAL SET-UP

The 'B' pair of nets (surface and bottom) were located perpendicularly to the south wall of the channel and abutted with the 'A' nets near the distal end of the bubble screen. 'B' nets were 3.7 m and 4.6 m long at diffuser angles of 45° and 30°, respectively. A 6 m gap existed between surface and bottom nets.

Nanticoke TGS forebay channel is about 9 m deep in the area where the study was conducted (Figure 1) and thus no attempt was made to sample the entire water column.

2.4 Experimental Procedure

Experiments involving lights and a diffuser angle of 45° were conducted between September 19-23, 1983 while tests at a diffuser angle of 30° (no lights) were performed during September 27-30 and November 21-24, 1983.

Each test was of 2 h duration. Control experiments consisted of setting gill nets without lights or air bubbler on. It was not possible to obtain matched pairs of replicates for all tests. The sampling frequency is shown in Table 1.

TABLE 1

SAMPLING FREQUENCY FOR EACH TEST TYPE

Test Type	Diffuser Angle at 45°		Diffuser Angle at 30° (Night Tests Only)	
	Day	Night	Sept	Nov
Bubbles + Light	3	2	-	-
Bubbles	2	2	5	5
Lights	4	3	-	-
Control	2	2	4	5

For tests involving the bubble screen, the air was turned off after gill nets were pulled. At the end of each test, all fish captured were identified to species and counted. Surface and bottom, and 'A' and 'B' catches were kept separate. The direction that fish were swimming when captured was noted. A sample of up to 5 fish of each species was measured for total length after each test.

Surface water temperature (°C), dissolved oxygen (ppm) and water turbidity (N.T.U.) measurements were made upstream and downstream of the bubble screen during most tests. Current velocity measurements were taken at 2 depths (near surface and 3 m) and at the north side, south side and centre of the forebay channel.

2.5 Data Analysis

Since fish density was generally low during each test, data analysis was performed for all fish species combined. Only fish caught with a downstream orientation were used in statistical tests.

Fish catch in each of the four gill net panels (surface A, bottom A, surface B, bottom B) was expressed as catch per 3.7 m of net (45° tests) or catch per 4.6 m of net (30° tests). A ratio of catch per unit effort was calculated as CUE of B/CUE of A for surface and bottom sets. In order to avoid a ratio of infinity each ratio was transformed by adding 1 to the numerator and denominator.

Analysis of variance (ANOVA) was performed on the transformed catch ratios of surface and bottom sets separately for both 45° and 30° tests. A multiple comparison test was used when more than 2 factors were involved and a significant ANOVA test was obtained.

3.0 RESULTS AND DISCUSSION

3.1 Response of Fish to Bubble Screen

Overall, fish did not appear to be directed by an air bubble screen (illuminated or not) set up near the eastern end of Nanticoke TGS forebay. For tests conducted during the day with the diffuser angle at 45°, no significant differences ($p>0.05$; $F=1.511$) were found among the four treatment conditions (bubbles + lights, bubbles alone, lights alone and control) with respect to the B/A surface gill net catch ratio (Table 2; Appendix 1). However, surface catch ratios in general were significantly higher ($p<0.05$; $F=5.877$) during night tests (Table 2; Appendix 1).

Significant differences ($p<0.05$; $F=7.970$) occurred among the treatment conditions (45° diffuser angle) with respect to the bottom B/A gill net catch ratio (Table 2; Appendix 1). The following associations were identified using Scheffé's multiple comparison test (Kleinbaum and Kupper, 1978):

	Lowest Ratio		Highest Ratio	
Treatment Group	Lights	Bubbles + Lights	Bubbles	Control
Mean of Day/Night Catch Ratios	1.12	1.47	1.73	3.45

These results indicate that on average proportionately more fish were captured in the B gill net situated near the bottom at the south side of the Nanticoke TGS forebay channel under control conditions (no bubbles or lights) than under experimental conditions, for both day and night tests. It is possible that fish taken near the bottom of the channel were responding differently to the presence of a bubble screen than fish located in the surface waters. This result may have been related to poor illumination of the lower portion of the bubble screen.

There were no significant differences found between bubble and control tests for surface or bottom gill net catch ratios during either September or November tests in which the diffuser angle was set at 30° (Table 2; Appendix 1). Thus the bubble screen did not direct fish within the channel, even when positioned at a narrow angle (30°) with respect to the longitudinal axis of the channel. The catch ratios derived from tests at 30° conducted in late September were slightly larger than those obtained either from tests at 45° or from tests at 30° conducted in November (Table 2).

3.2 Fish Species Composition

Diurnal distribution of fish in the intake forebay may have been linked to the nature of fish response to the air bubble screen. A list of fish species caught is contained in Appendix 2. Overall, the number of fish collected in the vicinity of the diffuser was relatively low, particularly during tests conducted at a diffuser angle of 45° (Tables 3 and 4; Appendix 3). Alewife (*Alosa pseudoharengus*) was the most numerous species taken during the entire study and generally showed highest abundance in surface waters at night (Table 4).

Both yellow perch (*Perca flavescens*) and white perch (*Morone americana*) were caught mainly in bottom gill net sets regardless of the experimental condition (Tables 3 and 4). Yellow perch were much more prevalent in day catches, a result which probably reflects their habit of resting on the bottom at night (Scott and Crossman, 1973). In laboratory tests, yellow perch were effectively deterred by air bubbles during the day but not at night (Ontario Hydro Research Division Report No 84-146-K). Stewart (1981) found that bottom-oriented fish passed readily through an air curtain. Stauffer et al. (1983) indicated that an air bubble barrier alone may not be an efficient exclusion system for white perch, which freely penetrated an air bubble curtain.

TABLE 2

MEAN TRANSFORMED RATIOS (B/A) OF CATCH PER UNIT EFFORT
(ALL SPECIES COMBINED)

	Tests with Diffuser at 45°							
	Surface Nets				Bottom Nets			
	Bubbles + Lights	Bubbles	Lights	Control	Bubbles + Lights	Bubbles	Lights	Control
Day	1.00±0.00*+ (n=3)	1.00±0.00+ (n=2)	0.88±0.25 (n=4)	1.00±0.00+ (n=2)	2.13±0.76 (n=3)	1.15±1.06 (n=2)	0.70±0.22 (n=4)	3.35±0.50 (n=2)
Night	3.35±2.18 (n=2)	3.25±2.05 (n=2)	1.20±0.44 (n=3)	1.10±0.42 (n=2)	0.80±0.30 (n=2)	2.30±2.12 (n=2)	1.53±0.42 (n=3)	3.55±0.21 (n=2)

	Tests with Diffuser at 30° (Night Only)			
	September Tests		November Tests	
	Bubbles	Control	Bubbles	Control
Surface Nets	3.94±2.39 (n=5)	4.00±3.22 (n=4)	2.90±2.80 (n=5)	3.48±3.06 (n=5)
Bottom Nets	3.80±2.25 (n=5)	4.48±2.15 (n=4)	1.10±0.66 (n=5)	2.61±1.51 (n=5)

* Values are mean ± standard deviation

n = number of replicates for each test type
+ = no fish caught

TABLE 3

SUMMARY OF FISH SPECIES COMPOSITION DURING TESTS WITH DIFFUSER AT 45°

Species	Bubbles with Lights				Bubbles Without Lights				Lights Only				No Bubbles or Lights				Totals
	Day (n=3)		Night (n=3)		Day (n=2)		Night (n=2)		Day (n=4)		Night (n=3)		Day (n=2)		Night (n=2)		
	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B	
Alewife	0	0 (9)	27 (2)	4 (129)	0	4 (3)	57 (83)	22 (25)	0	10 (21)	3 (17)	38 (36)	0	5 (7)	5 (10)	54 (13)	229 (355)
Yellow Perch	0	57 (41)	0	0 (1)	0	26 (21)	0	1 (1)	0 (1)	58 (51)	0 (3)	0	0 (1)	21 (32)	0	2 (3)	165 (155)
Gizzard Shad	0 (1)	0	4 (2)	0 (2)	0	1 (1)	20 (10)	1	0	2 (2)	0	1	0 (2)	1	5 (14)	1 (5)	36 (39)
White Bass	0 (1)	0 (3)	10	0	0	0 (1)	15	2	4	0 (1)	0 (1)	0 (1)	0	0 (1)	2 (4)	1 (2)	34 (15)
White Perch	0	4 (1)	0	0	0	2 (2)	0	3 (4)	1	3 (3)	0	0 (2)	0	1	0	4 (4)	18 (16)
Smallmouth Bass	0	0	0	0	0	0 (1)	0	0	1 (2)	0 (2)	0 (1)	0	0	0	0	0	1 (6)
Rock Bass	0	0	0	0	0	0	0	0	0	0	0	1(2)	0	0	0	0(1)	1(3)
White Sucker	0	0	0	0	0	0	0	0	0	0(1)	0	0	0	0	0	0	0(1)
Walleye	0	0	0	0	0	0(1)	0	0	0	0	0	0	0	0	0	0	0(1)
Longnose Gar	0	0	0	0	0	0	0	0	0	0	0(1)	0	0	0	0	0	0(1)
Totals	0 (2)	61 (54)	41 (4)	4 (132)	0	33 (30)	92 (93)	29 (30)	6 (3)	73 (81)	3 (23)	40 (41)	0 (3)	28 (40)	12 (28)	62 (28)	484 (592)

n = number of replicates
S = surface gill net; B = bottom gill net
Numbers of fish oriented downstream not in brackets
Numbers of fish oriented upstream in brackets

TABLE 4

SUMMARY OF FISH SPECIES COMPOSITION DURING TESTS WITH DIFFUSER AT 30° (NIGHT TESTS)

Species	Bubbles Only		No Bubbles		
	Surface (n=10)	Bottom (n=10)	Surface (n=9)	Bottom (n=9)	Totals
Alewife	190(300)	23(22)	286(218)	23(12)	522(552)
Gizzard Shad	84(25)	15(12)	3(9)	13(4)	115(50)
Yellow Perch	2(8)	11(16)	1(1)	12(12)	26(37)
White Bass	2(3)	3(2)	3(7)	2	10(12)
White Perch	2	6	0(1)	5(2)	13(3)
Rock Bass	3(2)	1	9(4)	0	13(6)
Walleye	0	0(1)	0	0	0(1)
Smallmouth Bass	0(1)	0	0	0	0(1)
Freshwater Drum	0	0	0	2	2
White Crappie	0	0	1	0	1
Rainbow Smelt	1	0	1	0(1)	2(1)
Totals	284(339)	59(53)	304(240)	57(31)	704(663)

n = number of replicates (September and November tests combined)

Numbers of fish oriented downstream not in brackets
Numbers of fish oriented upstream in brackets

Although white bass (*Morone chrysops*) occurred in surface and bottom waters, more often than not this species was taken in surface gill net sets (Tables 3 and 4). Similarly the largest numbers of gizzard shad (*Dorosoma cepedianum*) were caught in surface waters, especially at night (Tables 3 and 4). Thus the major species present in surface waters at night were alewife, gizzard shad and, to a lesser extent, white bass. Physical factors other than light intensity may have influenced the response of these species to the air bubble screen used in this study.

Fish length ranged from 11.3 - 50.8 cm (Appendix 4), but did not appear to affect the response of fish to the bubble screen.

3.3 Physical Factors

Physical factors which could have influenced the results obtained in this study include current regime, water level, turbidity and the gap between surface and bottom nets on the south side of the channel. The extent to which these factors, either singly or in combination, influenced the effectiveness of the bubble screen is not known.

The mean surface current velocity measured in the forebay channel was 9.2 $cm.s^{-1}$ and ranged from 0.0 - 41.0 $cm.s^{-1}$ (n=53); mean current velocity at about 3 m depth was 8.9 $cm.s^{-1}$ with a range of 1.0 - 24.0 $cm.s^{-1}$ (n=53). The mean velocity recorded in the field was about half of that measured in laboratory experiments (Ontario Hydro Research Division Report No 82-362-K and No 83-266-K). Further, current velocities were quite variable (Appendix 5) and averaged 12.5 $cm.s^{-1}$ (n=36), 8.6 $cm.s^{-1}$ (n=36) and 6.1 $cm.s^{-1}$ (n=34) at the north, centre and south sides of the channel, respectively. These observations, together with the fact that control tests were often associated with high B/A catch ratios (Table 2), suggest that fish may have preferred to move along the south side of the channel where a low velocity zone existed.

An unforeseen problem was the periodic fluctuation of the water level in the Nanticoke TGS forebay. Water depth temporarily increased by up to 1 m on several occasions and caused a rocky shelf area near the proximal (northern) end of the diffuser to be submerged, possibly providing an area for fish to pass around the surface portion of the bubble screen. In addition, the gap between upper and lower gill nets increased with each rise in water level, resulting in a larger passage for fish to go through at the southern side of the channel (refer to Figure 2). Free movement of fish between surface and bottom gill nets would have been enhanced by the lower velocities occurring near the southern side of the forebay.

The non-uniform cross-flow in the channel is also likely to have influenced the cohesiveness of the bubble screen by disrupting the bubble pattern both spatially and temporally.

Water turbidity averaged 4.9 N.T.U. (range = 0.9 - 9.6 N.T.U.: n = 21) upstream and 4.7 N.T.U. (range = 0.8 - 9.1 N.T.U.: n = 20) downstream of the bubble diffuser, respectively, during testing periods (Appendix 6). Thus the water turbidity near the experimental area was not increased by bubble diffuser operation.

Illumination of the lower portion of the air bubble screen (see methods) may have been inadequate to allow visual perception of the bubble curtain by fish. Light intensity in the upper 3 m of the water column was equal to or greater than that used in laboratory experiments in which air bubbles were found to effectively exclude alewife (OHRD Report No 83-266-K).

Approximately 50% of all fish captured during test periods were oriented in an upstream direction when gill nets were retrieved (Tables 3 and 4). This suggests that some fish were positioned downstream of the diffuser prior to the start of each test. Casual observations confirmed that fish were present in the surface waters downstream of the diffuser near the tempering pumps before, during and after tests. It is also possible that fish which circumvented the bubble screen by passing through the gap between surface and bottom nets may have reversed direction once they passed the entire gill net array.

Dissolved oxygen levels and water temperature were normal during testing periods (Appendix 6).

4.0 CONCLUSION AND RECOMMENDATIONS

Under the field conditions observed in the Nanticoke TGS forebay during testing periods, an air bubble screen failed to direct fish of any species.

The following conditions should be met if future testing is planned.

1. Tests should be conducted at a location with a relatively uniform current velocity profile and with current velocities exceeding 30 $cm.s^{-1}$.

2. Tests should be conducted with illumination of the entire air bubble screen.

3. The experimental design should take into account the possible preference by the fish of the low current velocity zones near the sides of the channel.

4. A gap between upper and lower sampling nets should be avoided.

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APPENDIX 1

RESULTS OF ANOVA TESTS

A. 45° Experimental Trials

1. Surface (2-way ANOVA using unweighted means)

Source	df	SS	MS	F-ratio
Day/Night	1	3.15	3.15	5.88*
Exp Condition	3	2.44	0.81	1.51
Interaction	3	2.20	0.73	1.36
Error	12		0.54	

2. Bottom (2-way ANOVA using unweighted means)

Source	df	SS	MS	F-ratio
Day/Night	1	0.09	0.09	0.33
Exp Condition	3	6.47	2.16	7.97*
Interaction	3	1.82	0.61	2.25
Error	12		0.27	

B. 30° Experimental Trials

1. September (2-way ANOVA)

Source	df	SS	MS	F-ratio
Exp Condition	1	0.11	0.11	0.03
Surface/Bottom	1	1.50	1.50	0.36
Interaction	1	0.39	0.39	0.09
Error	12	50.46	4.21	
TOTAL	15	52.46		

2. November (2-way ANOVA)

Source	df	SS	MS	F-ratio
Exp Condition	1	11.22	11.22	3.08
Surface/Bottom	1	6.85	6.85	1.88
Interaction	1	1.35	1.35	0.37
Error	12	43.79	3.65	
TOTAL	15	63.21		

---

* significant at P <0.05

APPENDIX 2

FISH SPECIES LIST

Rainbow Smelt	*Osmerus mordax*
Alewife	*Alosa pseudoharengus*
Gizzard Shad	*Dorosoma cepedianum*
White Perch	*Morone americana*
Yellow Perch	*Perca flavescens*
White Bass	*Morone chrysops*
Rock Bass	*Ambloplites rupestris*
Smallmouth Bass	*Micropterus dolomieui*
Walleye	*Stizostedion vitreum*
Freshwater Drum	*Aplodinotus grunniens*
White Crappie	*Pomoxis annularis*
White Sucker	*Catostomus commersoni*
Longnose Gar	*Lepisosteus osseus*

APPENDIX 3

FISH CATCH DATA

NB - Values are presented as a ratio of $\frac{\text{catch in B net}}{\text{catch in A net}}$, with numbers in brackets representing fish oriented upstream when caught.

A. Day Tests with Bubbles and Lights (45°)

Species	Surface Rep 1	Surface Rep 2	Surface Rep 3	Bottom Rep 1	Bottom Rep 2	Bottom Rep 3
Yellow Perch	0/0	0/0	0/0	5(3)/19(22)	2(1)/0	7(3)/24(12)
White Perch	0/0	0/0	0/0	1/1(1)	0(1)/0(2)	0/2
Alewife	0/0	0/0	0/0	0/0(3)	0/0	0/0(3)
White Bass	0/0	0/0	0/0(1)	0/0(1)	0/0	0/0(1)
Gizzard Shad	0/0	0/0	0/0(1)	0/0	0/0	0/0

B. Night Tests with Bubbles and Lights (45°)

Species	Surface Rep 1	Surface Rep 2	Bottom Rep 1	Bottom Rep 2
Alewife	2/22(2)	2/1	0/1(13)	0(25)/0(85)
White Bass	2/1	5/0	0/0	0/0
Gizzard Shad	0/0	1(1)/3	0(2)/0	0/0

APPENDIX 3 (Contd)

FISH CATCH DATA

C. Day Tests with Bubbles Only (45°)

Species	Surface Rep 1	Surface Rep 2	Bottom Rep 1	Bottom Rep 2
Yellow Perch	0/0	0/0	0(3)/9(6)	6(4)/11(8)
Gizzard Shad	0/0	0/0	0/0	0/1(1)
Alewife	0/0	0/0	0/0	0/4(3)
White Perch	0/0	0/0	0/0	0/2(2)
White Bass	0/0	0/0	0/0	0/0(1)
Walleye	0/0	0/0	0/0	0/0
Smallmouth Bass	0/0	0/0	0(1)/0	0/0(1)

D. Night Tests with Bubbles Only (45°)

Species	Surface Rep 1	Surface Rep 2	Bottom Rep 1	Bottom Rep 2
Alewife	1/0	6/8(14)	25(5)/21(78)	1(2)/9(7)
White Perch	0/0	1/1(3)	0/0	0/1(1)
Gizzard Shad	2(4)/19(6)	0/1	1/0	0/0(1)
White Bass	6/8	1/1	0/1	0/0
Yellow Perch	0/0	1/0	0/0	0/0

APPENDIX 3 (Contd)

FISH CATCH DATA

E. Day Tests with Lights Only (45°)

Species	Surface Rep 1	Surface Rep 2	Surface Rep 3	Surface Rep 4	Bottom Rep 1	Bottom Rep 2	Bottom Rep 3	Bottom Rep 4
Yellow Perch	0 / 0(1)	0 / 0	0 / 0	0 / 0	3(6) / 31(23)	1 / 15(13)	0 / 4(2)	1 / 3(7)
Alewife	0 / 0	0 / 0	0 / 0	0 / 0	0(1) / 1(8)	0 / 5(3)	0 / 1(6)	0 / 2(4)
White Perch	0 / 1	0 / 0	0 / 0	0 / 0	0 / 1(1)	0 / 0	0 / 0	0(1) / 2(1)
Gizzard Shad	0 / 0	0 / 0	0 / 0	0 / 0	0 / 1(2)	0 / 1	0 / 0	0 / 0
White Bass	0 / 4	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0(1)	0 / 0
Smallmouth Bass	1 / 0	0 / 0	0(1) / 0(1)	0 / 0	0 / 0	0 / 0(1)	0 / 0	0 / 0(1)
White Sucker	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0(1)	0 / 0	0 / 0

F. Night Tests with Lights Only (45°)

Species	Surface Rep 1	Surface Rep 2	Surface Rep 3	Bottom Rep 1	Bottom Rep 2	Bottom Rep 3
Alewife	1(3) / 1(11)	0 / 1	0(1) / 0(20	4(20) / 8	0 / 0	5 / 21
White Bass	0 / 0	0 / 0(1)	0 / 0	0(1) / 0	0 / 0	0 / 0
Rock Bass	0 / 0	0 / 0	0 / 0	0(1) / 2	0 / 0	0 / 0
White Perch	0 / 0	0 / 0	0 / 0	0 / 0(2)	0 / 0	0 / 0
Yellow Perch	0(1) / 0(2)	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0
Gizzard Shad	0 / 0	0 / 0	0 / 0	0 / 0	1 / 0	0 / 0
Longnose Gar	0 / 0	0 / 0	0(1) / 0	0 / 0	0 / 0	0 / 0
Smallmouth Bass	0 / 0	0 / 0	0 / 0(1)	0 / 0	0 / 0	0 / 0

APPENDIX 3 (Contd)

FISH CATCH DATA

G. Day Control Tests (45°)

Species	Surface Rep 1	Surface Rep 2	Bottom Rep 1	Bottom Rep 2
Yellow Perch	0/0	0(1)/0	5(4)/0	4(2)/6(22)
Alewife	0/0	0/0	0/1(1)	2/2(6)
Gizzard Shad	0/0	0(1)/0(1)	1/0	0/0
White Bass	0/0	0/0	0/0(1)	0/0
White Perch	0/0	1/0	0/0	0/1

H. Night Control Tests (45°)

Species	Surface Rep 1	Surface Rep 2	Bottom Rep 1	Bottom Rep 2
Alewife	1/3(10)	0/1	17/25(5)	7(2)/5(6)
Gizzard Shad	1(2)/3(11)	0/1(1)	0(5)/0	1/0
Yellow Perch	0/0	0/0	0(1)/0	0/2(2)
White Perch	0/0	0/0	0(1)/1(2)	0/3(1)
Rock Bass	0/0	0/0	0(1)/0	0/0
White Bass	0/2(4)	0/0	0/0	0/1(2)

APPENDIX 3 (Contd)

FISH CATCH DATA

I. Night Tests with Bubbles (30°) in September

Species	Surface Rep 1	Surface Rep 2	Surface Rep 3	Surface Rep 4	Surface Rep 5	Bottom Rep 1	Bottom Rep 2	Bottom Rep 3	Bottom Rep 4	Bottom Rep 5
Yellow Perch	0/0	0/0(1)	0/1(1)	0/0	0/0	1(2)/0(1)	1(1)/0	0(2)/0	3(1)/0	4(5)/0(1)
Alewife	5(7)/7(21)	2(1)/11(8)	4(1)/6(5)	11(4)/21(28)	1/7(6)	0(1)/0(3)	0(1)/2(2)	0/0(2)	0(1)/2	0/0(2)
Walleye	0/0	0/0	0/0	0/0	0/0	0(1)/0(1)	0/0	0/0	0/0	0/0
White Bass	0/0	0/0	0/0	0/0	0/0	0/0(1)	0/0	0/0	1/0	0/0
Gizzard Shad	1(1)/0	2(1)/0	21/6(4)	9(2)/4(1)	17(3)/12(7)	0/0	2/1(2)	1(4)/0	2/0	3(3)/1(2)
White Perch	0/0	0/0	0/0	0/0	0/0	0/0	0/0(1)	0/0	0/0	0/0
Rock Bass	0/0	0/0	1/0	0/1	0(1)/0(1)	0/0	0/0	0/0	1/0	0/0
Smallmouth Bass	0/0	0/0	0/0	0/0(1)	0/0	0/0	0/0	0/0	0/0	0/0

J. Night Control Tests (30°) in September

Species	Surface Rep 1	Surface Rep 2	Surface Rep 3	Surface Rep 4	Bottom Rep 1	Bottom Rep 2	Bottom Rep 3	Bottom Rep 4
Alewife	9(8)/3(12)	5(5)/1(16)	0/1	0/1	4(1)/0(3)	3/1	0/0	3/1
Yellow Perch	0/0	0/0(1)	1/0	0/0	2(2)/0	0(2)/0(3)	2(1)/2(1)	0/0
White Bass	0/0(1)	0(1)/0	0/0	0/0	0/0	0/0	1/1	0/0
Freshwater Drum	0/0	0/0	0/0	0/0	0/1	0/0	0/1	0/0
Gizzard Shad	1(3)/1(2)	1(1)/0	1/1	0/0(1)	0/0	2/0	3(1)/3(1)	0/3(1)
White Perch	0/0	0/0	0/0	0/0	0(1)/0	2/0	0/0	0/0
Rock Bass	0/0	3/0(1)	0/2	0/0(1)	0/0	0/0	0/0	0/0
White Crappie	0/0	0/1	0/0	0/0	0/0	0/0	0/0	0/0

APPENDIX 3 (Concluded)

FISH CATCH DATA

K. Night Tests with Bubbles (30°) in November

Species	Surface					Bottom				
	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5
Yellow Perch	0 / 0(2)	0 / 0	0(2) / 1(2)	0 / 0	0 / 0	0 / 0(1)	0 / 2(1)	0 / 0	0 / 0	0(1) / 0
Alewife	5(6) / 35(35)	28(41) / 15(51)	12(5) / 19(37)	4(10) / 10(28)	0(2) / 1(4)	0 / 2(1)	0 / 6(3)	0 / 2(4)	0(1) / 0(2)	0 / 0
White Perch	0 / 0	0 / 0	2 / 0	0 / 0	0 / 0	0(2) / 0	0 / 0	0 / 1	0 / 0	2 / 0
Gizzard Shad	1 / 0(2)	0 / 0(2)	0 / 0	2 / 9(2)	0 / 0	0 / 0	0 / 0	0 / 0	0(1) / 2	0 / 2
White Bass	0 / 0	0 / 0	0(1) / 0(1)	1 / 0(2)	0 / 0	0 / 0	0 / 0(1)	0 / 0	1 / 1	0 / 0
Rainbow Smelt	0 / 0	0 / 0	0 / 0	1 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0

L. Night Control Tests (30°) in November

Species	Surface					Bottom				
	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5
Alewife	61(15) / 45(20)	9(10) / 28(53)	16(21) / 69(49)	19(1) / 9(4)	1 / 9(4)	2 / 2	1(1) / 0	2(1) / 2(1)	1 / 1(5)	0 / 0
White Perch	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 3	0(1) / 0	0 / 0	0 / 0	0 / 0(1)
Rock Bass	0 / 0(1)	0 / 0(1)	0 / 0	0 / 3	1 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0
Rainbow Smelt	0 / 1	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0(1)	0 / 0	0 / 0
Yellow Perch	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	1 / 0	0 / 0	4 / 0	1(2) / 0(1)
White Bass	0 / 0	0 / 0	0(1) / 0(1)	2 / 1	0(2) / 0(1)	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0
Gizzard Shad	0 / 0	0 / 0	0 / 0(1)	3 / 0	0 / 2(1)	0 / 0	0 / 0	0 / 0	0 / 0	0 / 3

APPENDIX 4

FISH LENGTH DATA

Species	Length (cm)
Alewife n = 190	16.8, 15.8, 15.0, 13.7, 14.0, 16.9, 15.3, 14.3, 17.0, 16.5, 16.2, 16.5, 15.5, 16.0, 16. 15.5, 16.5, 16.5, 16.0, 16.5, 16.0, 16.5, 16.5, 16.0, 15.0, 15.5, 16.2, 15.2, 14.4, 15. 15.5, 16.1, 16.2, 14.9, 15.9, 17.0, 16.3, 16.4, 16.3, 16.5, 16.5, 15.5, 16.5, 16.0, 17. 16.0, 16.5, 16.0, 17.0, 17.8, 17.1, 16.5, 16.5, 15.2, 15.2, 15.2, 15.7, 14.5, 14.2, 15.2, 14.5, 14.2, 16.5, 15.0, 15.0, 15.0, 16.5, 15.5, 16.0, 17.0, 16.0, 17.0, 15.0, 16.5, 16.0, 15.0, 16.0, 15.0, 17.0, 15.2, 15.8, 16.6, 17.1, 14.3, 16.0, 15.3, 16.0, 15.0, 15.5, 16.0, 17.0, 17.0, 16.0, 16.5, 15.0, 16.5, 16.0, 16.5, 13.0, 16.5, 16.0, 15.5, 13.8, 15.2, 15.0, 17.0, 14.0, 16.9, 14.4, 16.6, 15.9, 14.2, 15.7, 15.3, 15.8, 15.6, 15.9, 14.8, 18.0, 16.1, 16.1, 14.5, 10.5, 15.9, 15.7, 15.2, 14. 15.5, 15.8, 15.3, 16.0, 16.2, 15.8, 15.0, 15.1, 16.0, 15.1, 15.2, 14.0, 15.8, 17.1, 16. 15.0, 16.2, 15.5, 15.2, 15.5, 16.8, 15.4, 14.1, 16.5, 16.8, 16.6, 15.6, 16.0, 16.6, 15.5, 16.5, 16.3, 16.7, 17.3, 17.0, 16.7, 15.9, 14.6, 16.5, 16.7, 17.2, 17.6, 17.3, 14.8, 15.5, 16.6, 16.6, 17.6, 15.8, 16.3, 16.2, 16.0, 16.3, 16.7, 15.3, 15.0, 17.1, 15.6, 14.8, 15.5, 15.0, 17.6.
Yellow Perch n = 113	14.5, 17.5, 17.0, 18.3, 14.5, 15.3, 21.0, 15.0, 17.2, 22.1, 16.2, 17.0, 16.4, 20.4, 15.6, 16.1, 16.8, 16.0, 17.4, 15.5, 18.0, 15.1, 16.8, 18.0, 15.0, 15.0, 15.0, 16.2, 16.5, 17.0, 16.0, 18.1, 16.3, 15.9, 18.3, 16.9, 17.3, 26.0, 16.8, 17.0, 15.3, 15.8, 18.5, 16.7, 14.8, 14.4, 17.5, 15.5, 19.6, 16.1, 15.5, 16.5, 16.6, 15.9, 15.0, 15.3, 16.0, 16.7, 18.7, 18.3, 17.9, 16.5, 18.7, 15.9, 16.8, 19.5, 24.0, 17.0, 17.5, 18.2, 15.2, 16.4, 15.8, 15.5, 15.8, 17.1, 18.6, 23.0, 25.0, 20.0, 14.0, 17.0, 16.2, 15.1, 18.0, 15.2, 16.3, 16.7, 15.9, 16.2, 17.5, 14.5, 21.2, 23.3, 17.2, 18.8, 20.2, 15.2, 16.5, 16.7, 15.4, 16.2, 18.9, 22.6, 23.0, 15.4, 17.0, 16.2, 20.5, 17.0, 16.5, 15.0, 16.5.
Gizzard Shad n = 97	15.7, 14.5, 15.5, 14.6, 13.3, 15.9, 16.5, 15.2, 15.4, 12.8, 15.2, 12.5, 14.3, 25.5, 26.0, 16.0, 17.0, 17.0, 17.0, 16.0, 14.0, 13.8, 16.3, 17.0, 15.0, 14.5, 13.0, 15.5, 15.0, 15.0, 16.0, 17.0, 17.0, 18.5, 15.0, 13.5, 12.0, 13.5, 15.2, 13.0, 13.4, 13.4, 15.5, 13.0, 13.2, 13.7, 15.6, 14.0, 14.3, 12.9, 13.4, 14.0, 13.8, 13.7, 14.6, 14.5, 14.0, 14.5, 14.1, 13.8, 13.0, 13.2, 15.0, 13.3, 17.0, 13.0, 15.5, 14.2, 13.3, 14.4, 15.1, 14.4. 14.3, 14.3, 14.2, 14.0, 20.0, 22.0, 18.3. 19.0, 16.9, 18.7, 14.6, 13.9, 18.5, 17.5, 19.0, 13.3, 18.3, 17.1, 18.0, 17.0, 21.3, 18.0, 17.8, 13.6, 16.1.
White Bass n = 55	17.3, 16.0, 23.2, 25.0, 16.0, 17.0, 24.8, 19.0, 19.0, 18.4, 15.9, 19.8, 23.1, 16.3, 15.5, 20.5, 25.5, 19.0, 22.5, 24.0, 18.0, 22.0, 20.0, 17.0, 25.5, 26.0, 16.5, 18.0, 15.5, 17.0, 17.5, 17.5, 26.0, 26.0, 27.3, 18.4, 25.0, 25.5, 22.5, 24.3, 17.5, 24.1, 12.8, 15.1, 23.0, 19.8, 23.8, 28.0, 25.0, 13.5, 12.0, 13.0, 11.8, 14.8, 13.3.
White Perch n = 45	15.1, 12.8, 14.2, 14.6, 12.2, 13.6, 13.1, 16.5, 15.0, 16.5, 17.5, 14.3, 14.0, 13.2, 12.5, 15.0, 13.0, 15.0, 16.5, 11.5, 12.5, 13.6, 15.6, 13.0, 16.5, 13.0, 15.0, 18.5, 26.0, 15.5, 16.1, 12.7, 11.3, 12.2, 13.1, 13.9, 13.3, 11.6, 13.0, 12.5, 13.3, 15.0, 15.5, 11.5, 13.0.
Rock Bass n = 23	18.0, 16.0, 17.5, 14.5, 22.1, 19.8, 22.2, 19.2, 20.8, 20.0, 22.0, 23.0, 21.0, 20.9, 22.0, 23.0, 20.0, 24.0, 20.7, 20.0, 18.2, 14.6, 23.3.
Smallmouth Bass n = 7	17.7, 15.4, 14.8, 14.5, 15.9, 14.8, 14.0.
Rainbow Smelt n = 3	15.0, 12.4, 15.3
Walleye n = 2	32.0, 29.0
Freshwater Drum n = 2	15.8, 15.3
White Sucker n = 1	17.9
White Crappie n =1	15.0
Longnose Gar n = 1	50.8

APPENDIX 5

CURRENT VELOCITY DATA

North Side of Forebay		Centre of Forebay		South Side of Forebay	
Surface	3 m	Surface	3 m	Surface	3 m
4.0	7.0	2.0	2.0	3.0	4.0
25.0	24.0	4.0	10.0	10.0	11.0
23.0	16.0	9.0	20.0	-	-
41.0	20.0	17.0	14.0	9.0	13.0
4.0	7.0	2.0	2.0	3.0	4.0
16.0	16.0	21.0	4.0	5.0	4.0
25.0	24.0	4.0	10.0	10.0	11.0
4.0	12.0	15.0	5.0	1.0	11.0
14.0	11.0	13.0	19.0	10.0	14.0
14.0	17.0	10.0	14.0	1.0	14.0
4.0	12.0	15.0	5.0	1.0	11.0
6.0	10.0	18.0	11.0	7.0	2.0
10.0	3.0	1.0	1.0	8.0	5.0
10.0	3.0	1.0	1.0	8.0	5.0
6.0	10.0	18.0	11.0	7.0	2.0
8.0	8.0	3.0	3.0	0.0	10.0
9.0	9.0	9.0	3.0	0.0	2.0
9.0	9.0	9.0	3.0	0.0	2.0

- no data
all values are $cm.s^{-1}$

APPENDIX 6

TURBIDITY, TEMPERATURE AND DISSOLVED OXYGEN DATA
Turbidity units in N.T.U.; Temperature as °C;
Dissolved Oxygen as ppm.

\- no data

Upstream of Diffuser Line					Downstream of Diffuser Line				
Turbidity	Temperature		Dissolved Oxygen		Turbidity	Temperature		Dissolved Oxygen	
	Surface	Bottom	Surface	Bottom		Surface	Bottom	Surface	Bottom
-	18.8	19.1	9.6	9.4	-	19.1	19.0	9.1	9.0
3.6	17.5	17.6	9.5	9.5	3.2	17.5	17.6	9.6	9.4
5.1	19.7	19.7	8.9	8.8	5.3	19.7	19.6	9.2	9.1
9.6	19.6	19.6	8.8	9.9	-	19.6	19.6	9.9	9.7
5.0	19.6	19.5	9.0	9.1	3.7	19.5	19.5	9.0	8.9
-	18.8	19.1	9.6	9.4	-	19.1	19.0	9.1	9.0
5.1	20.1	19.9	9.4	9.4	5.5	20.0	19.9	9.7	9.3
5.1	19.7	19.7	8.9	8.8	5.3	19.7	19.6	9.2	9.1
5.0	19.0	19.0	9.5	9.5	4.6	19.0	19.0	9.8	9.2
3.2	19.7	19.7	9.4	8.6	3.5	19.6	19.7	9.3	8.5
3.7	19.5	15.5	10.3	9.4	3.7	19.5	19.5	10.0	9.0
3.6	17.5	17.6	9.5	9.5	3.7	17.5	17.6	9.6	9.4
-	19.1	19.1	10.0	9.5	-	19.1	19.1	9.7	9.6
5.0	19.0	19.0	9.5	9.5	4.6	19.0	19.0	9.8	9.2
3.1	18.1	18.2	11.0	10.9	4.2	18.2	18.2	10.4	9.7
4.5	18.3	18.4	10.4	9.6	5.4	18.4	18.5	9.6	9.3
3.2	18.9	19.0	9.9	9.7	3.1	19.0	19.1	9.9	9.5
1.0	16.4	16.4	11.3	10.8	0.9	16.2	16.4	11.1	-
2.2	17.3	17.3	-	-	1.8	17.3	17.3	-	-
-	17.9	17.9	-	-	-	18.1	17.9	-	-
-	17.9	17.9	-	-	-	18.1	18.0	-	-
2.8	17.8	17.5	-	-	1.6	17.6	17.6	-	-
8.2	7.1	7.1	-	-	7.2	7.1	7.1	-	-
7.7	7.0	7.0	14.0	13.8	7.9	7.0	7.0	13.8	13.4
-	7.0	7.0	-	-	-	7.0	7.0	-	-
8.8	8.6	8.6	14.0	13.5	8.8	8.6	8.6	13.1	13.1
9.1	8.6	8.6	-	-	9.1	8.6	8.6	-	-
8.9	7.0	7.0	-	-	8.7	7.0	7.0	-	-